

REPLICA-BASED CRACK INSPECTION

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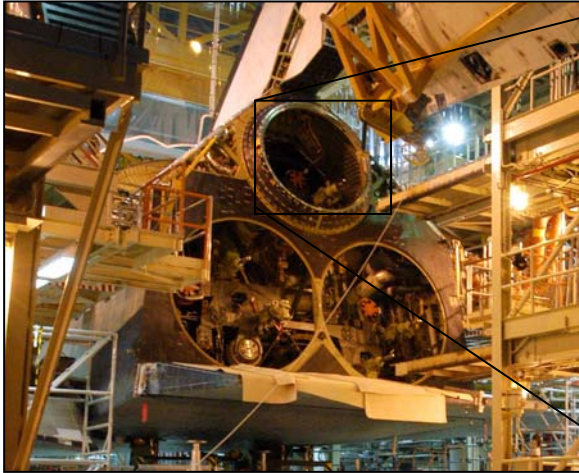
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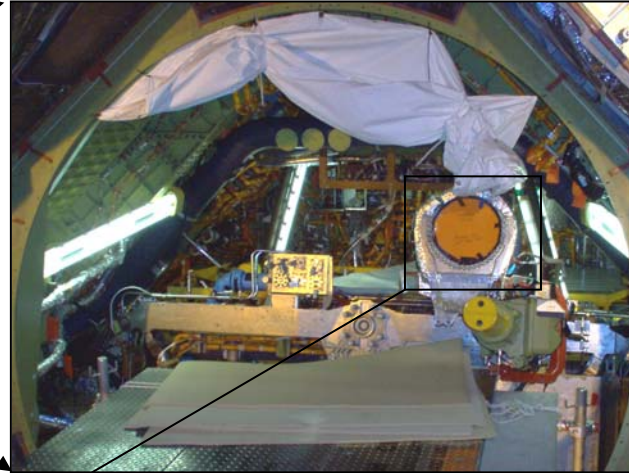
INTRODUCTION

- **Cracks found in Space Shuttle Main Engine LH₂ feedline flowliners (2002)**
 - Ranged from 0.1 inch to 0.6 inch long
 - Weld repaired, polished, and recertified for flight
 - NDE: no cracks >0.075 inches long exist
- **Revisited in 2004**
 - Unable to show flight rationale with a crack 0.075 inches long

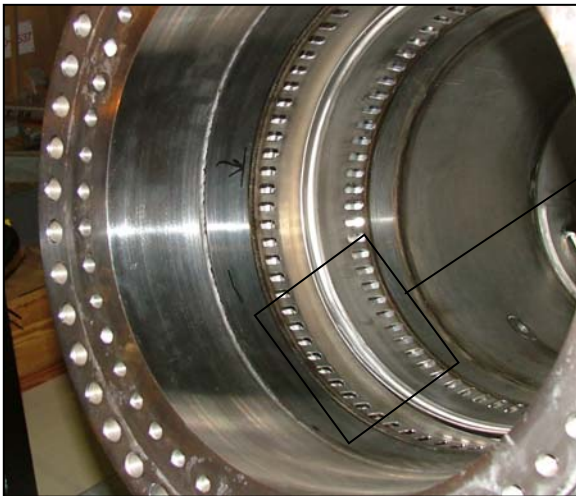
FLOWLINER DESCRIPTION



Orbiter aft



Engine cavity



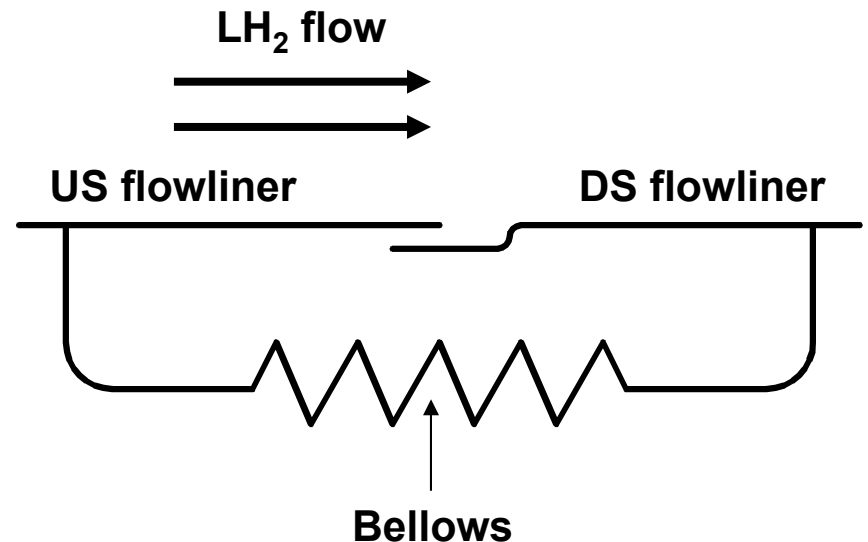
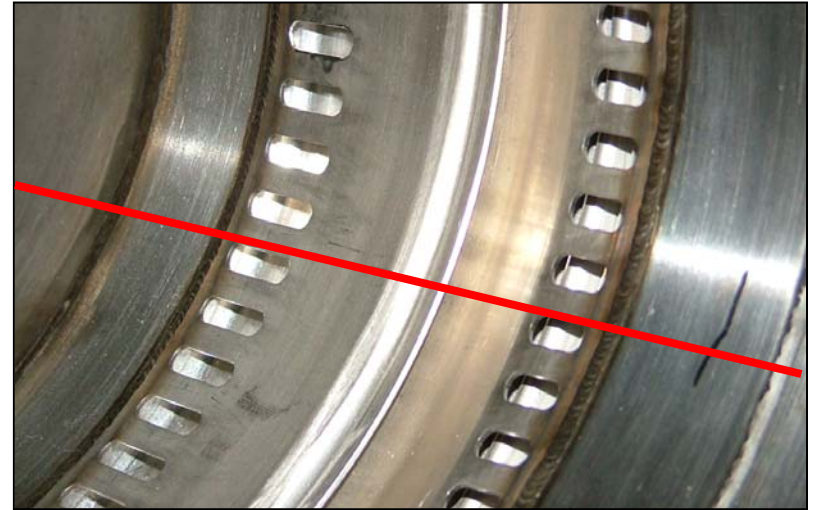
LH₂ feedline



Flowliners

FLOWLINER DESCRIPTION

- **LH₂ consumption**
 - 385,000 gallons
 - 8.5 minutes
 - Each engine consumes 15,000 gal/min
 - Flow induced stress cycles in kHz range
 - Millions of stress cycles per flight



PROBLEM

- **Analysis: unsafe conditions may occur for multiple cracks > 0.005 inch long**
- **Improved eddy current unable to detect 0.005-inch-long cracks**
- **Need an NDE method able to find cracks down to 0.005 inch long**

PROPOSED SOLUTION

- Use surface replicas as an NDE method
- Surface replicas used for decades to monitor small cracks (<0.005 inch)
- Recently-developed silicone-based replicas better suited for inspection



Acetate tape replica



Silicone-based replica dispenser

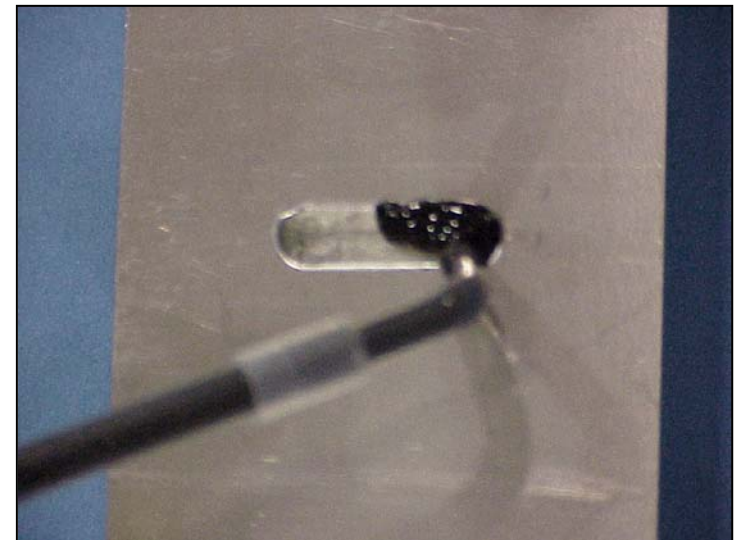
EXPERIMENTAL PLAN

- **Feasibility study:**
 - **Generate fatigue cracks in laboratory specimens**
 - **Compare crack lengths from**
 - **Silicone-based replicas (zero load)**
 - **Acetate-tape replicas (maximum load)**
 - **Destructive exam (zero load)**
- **Determine reliability of silicone-based replicas relative to acetate-tape replicas**



FATIGUE TESTING

- Specimens used to simulate flowliner slot geometry and stress state
 - $P_{max} = 3.4$ kips, $R = 0.1$
- Testing interrupted periodically for slot surface replication
 - Acetate-tape replicas
 - Silicone-based replicas



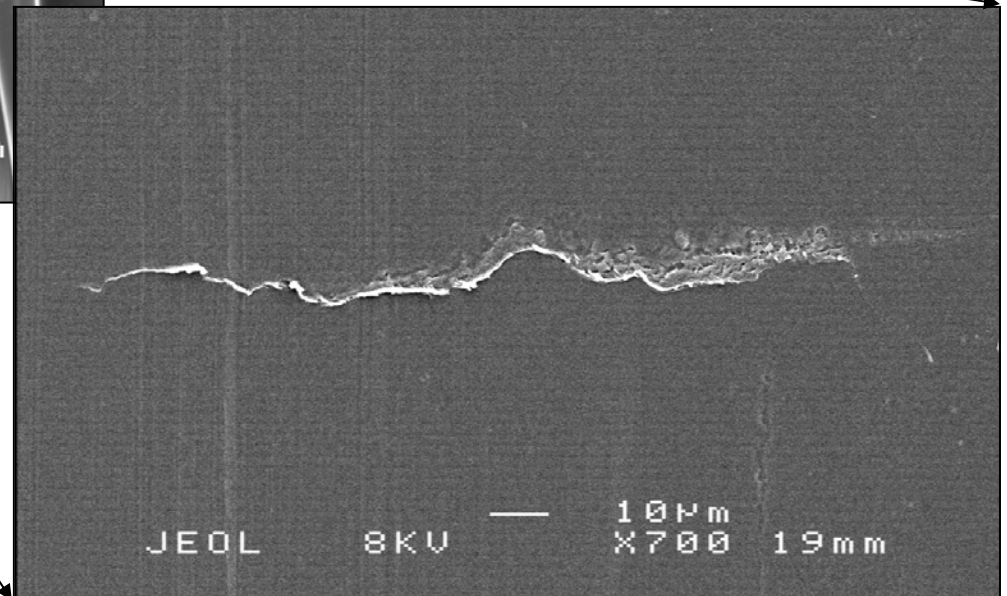
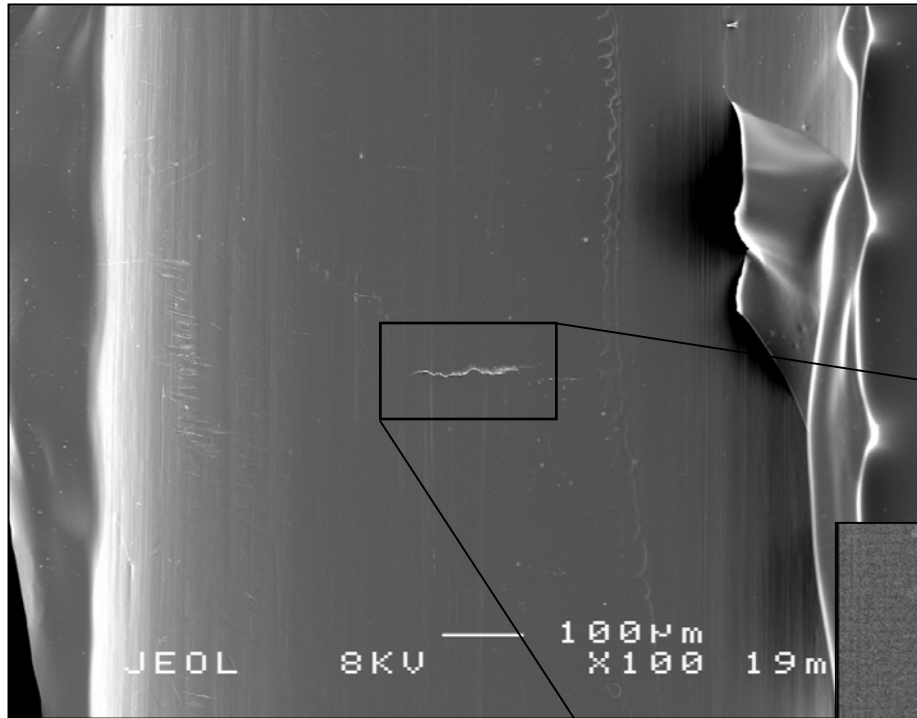
REPLICA ANALYSIS

- **Replica preparation**
 - Sectioned in 4 pieces
 - Grounded on metallic slide
 - Coated with metallic material
- **Examined in an SEM**
- **Initial scan at 50-100X**
 - Surface finish, scratches, etc.
- **Crack scan at 400-700X**

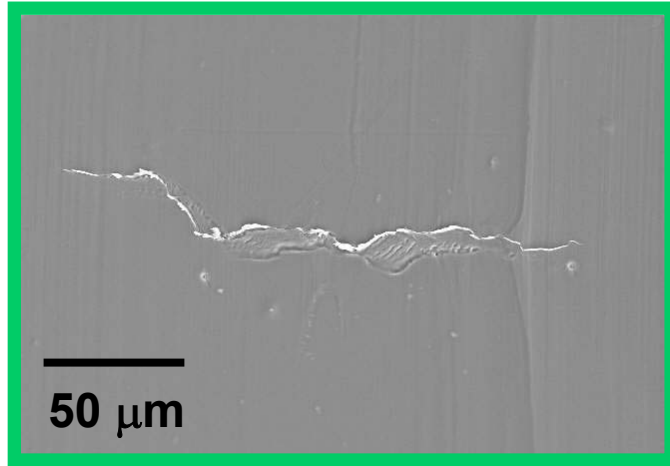


EXPERIMENTAL RESULTS

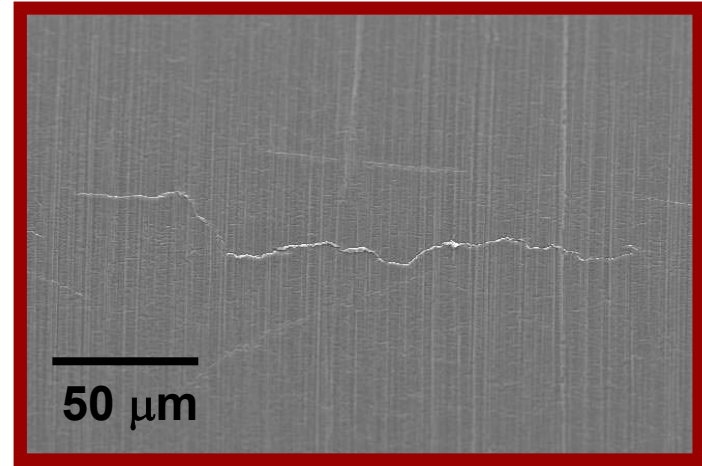
- Crack found after 50,000 cycles
 - Surface crack
 - 0.008 inches long



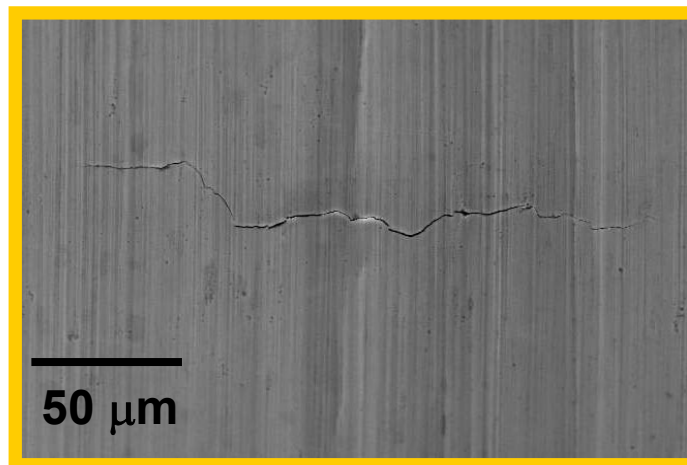
CRACK LENGTH COMPARISON



Acetate replica (loaded) – 163 μm

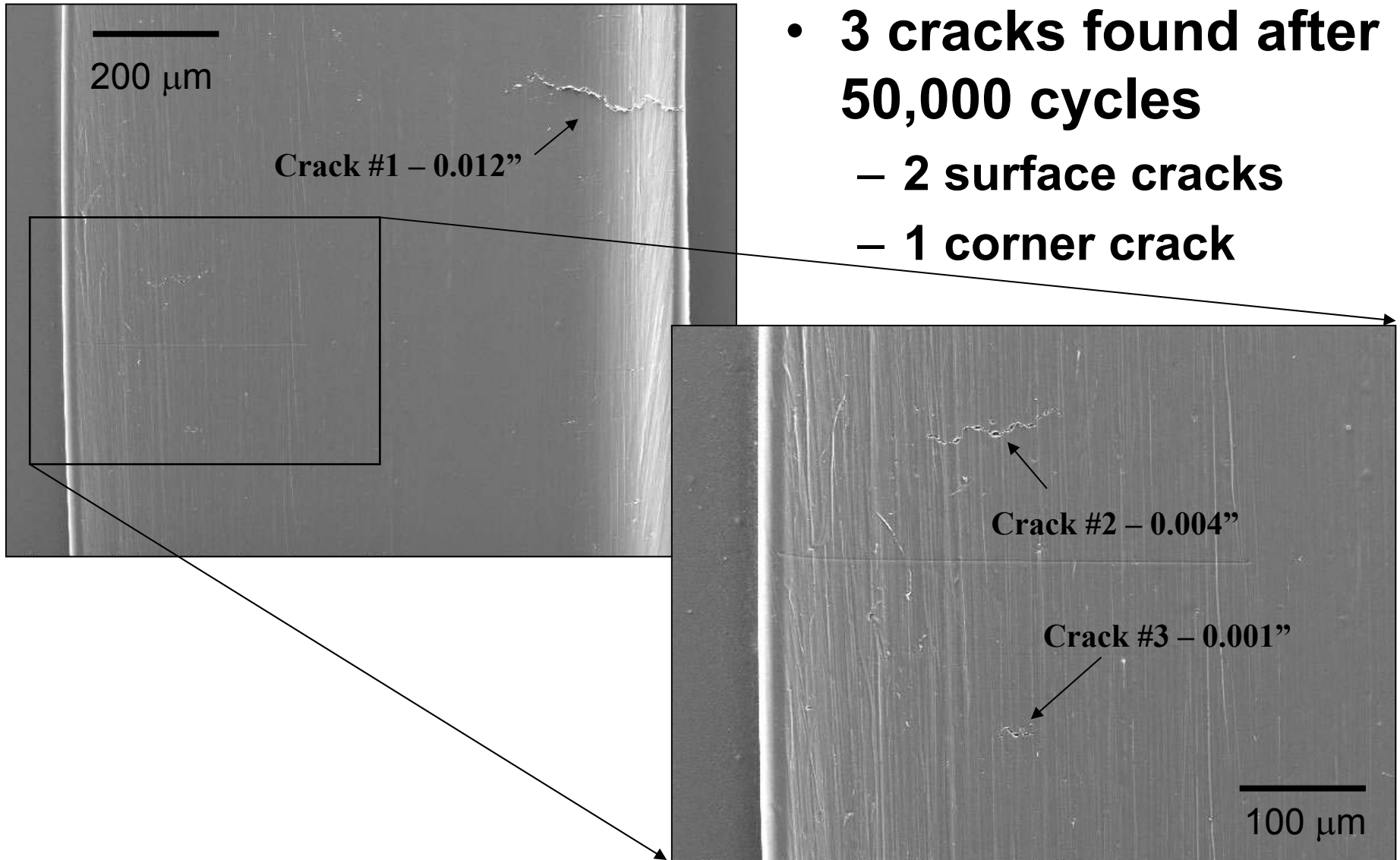


Silicone replica (no load) – 199 μm



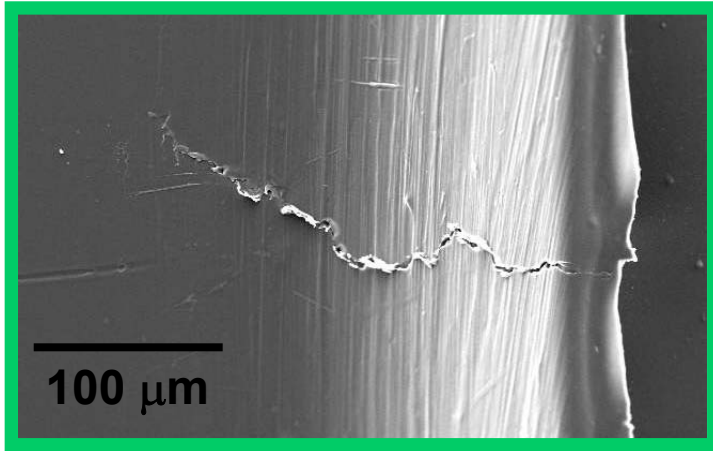
Specimen (no load) – 194 μm

EXPERIMENTAL RESULTS

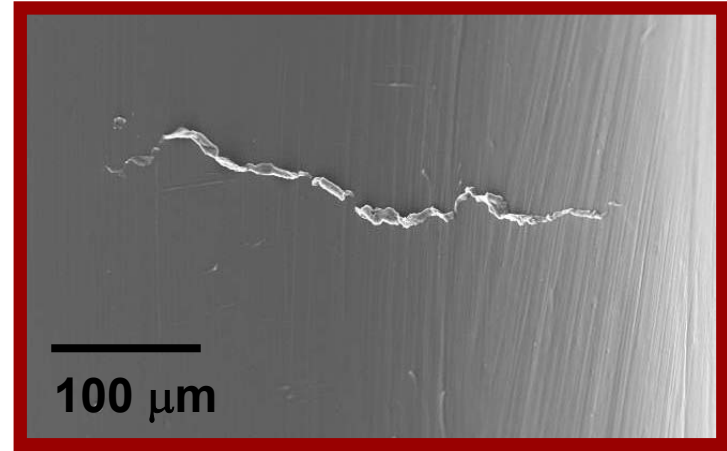


CRACK LENGTH COMPARISON

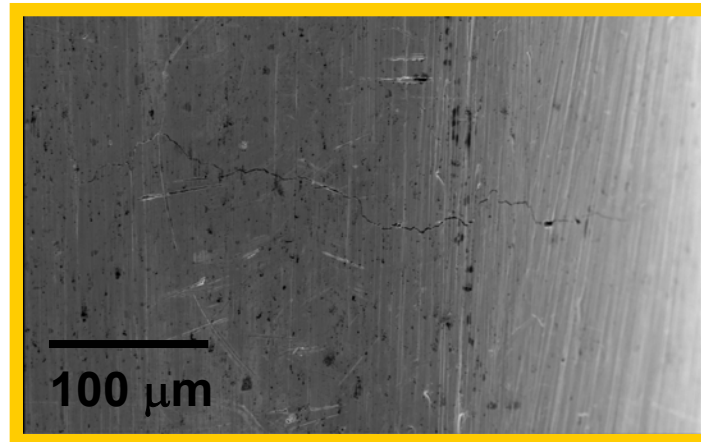
(Crack #1)



Acetate replica (loaded) – 280 μm



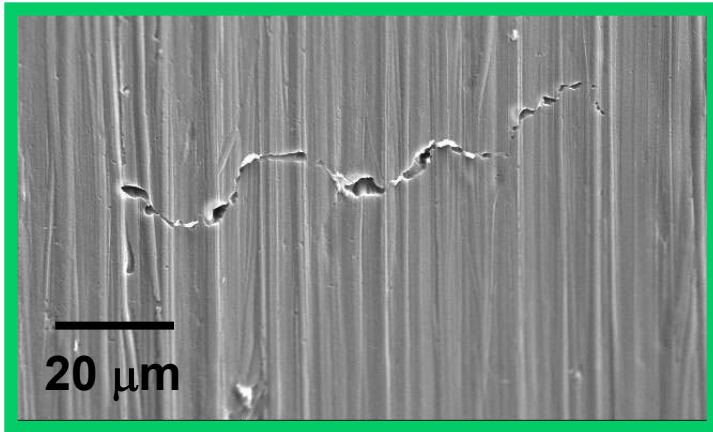
Silicone replica (no load) – 343 μm



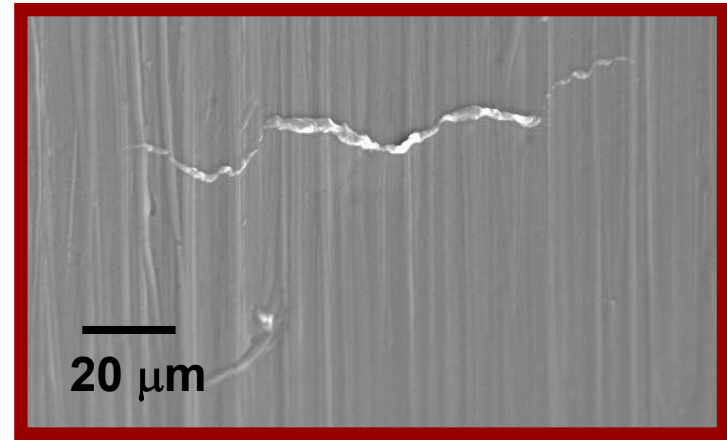
Specimen (no load) – 350 μm

CRACK LENGTH COMPARISON

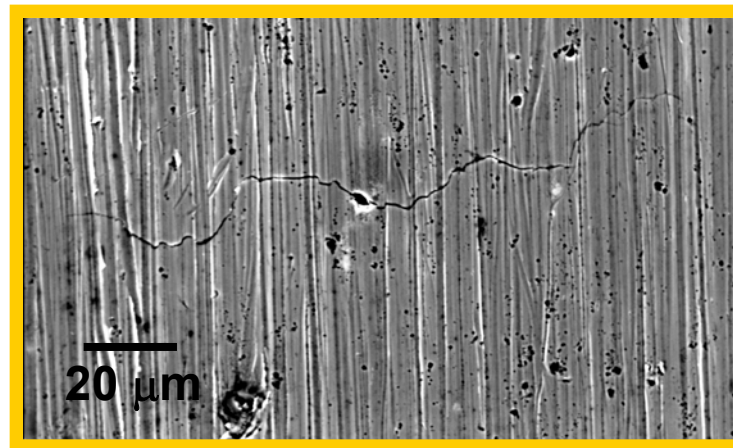
(Crack #2)



Acetate replica (loaded) – 81 μm



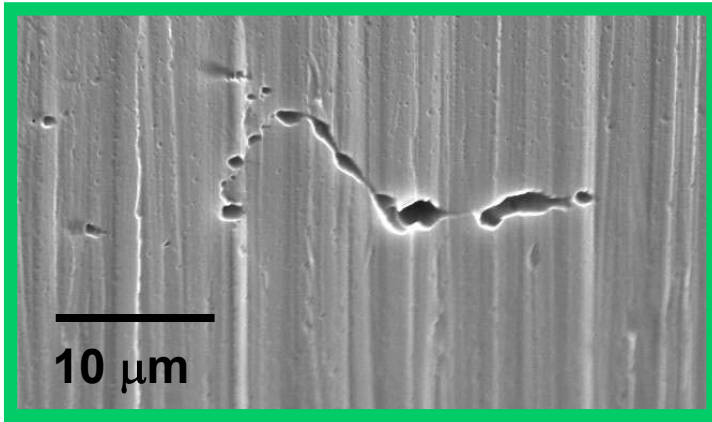
Silicone replica (no load) – 104 μm



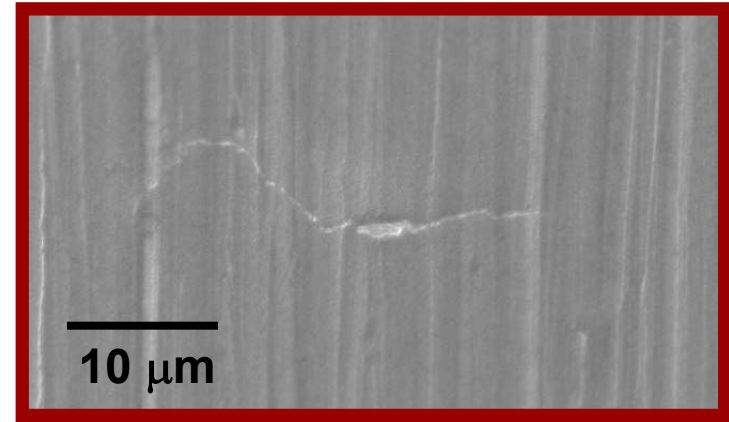
Specimen (no load) – 110 μm

CRACK LENGTH COMPARISON

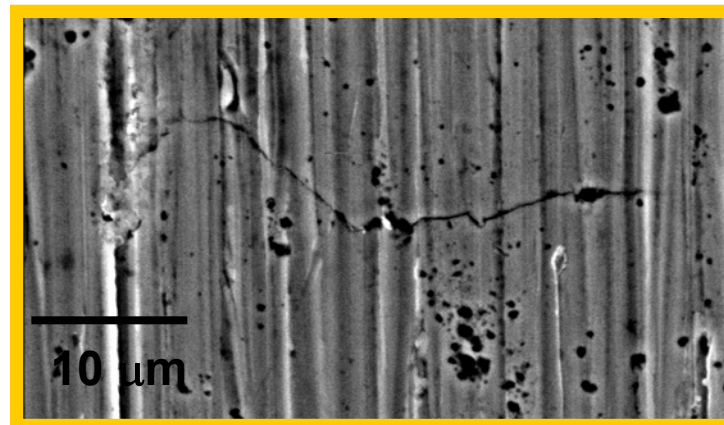
(Crack #3)



Acetate replica (loaded) – 20 μm



Silicone replica (no load) – 26 μm



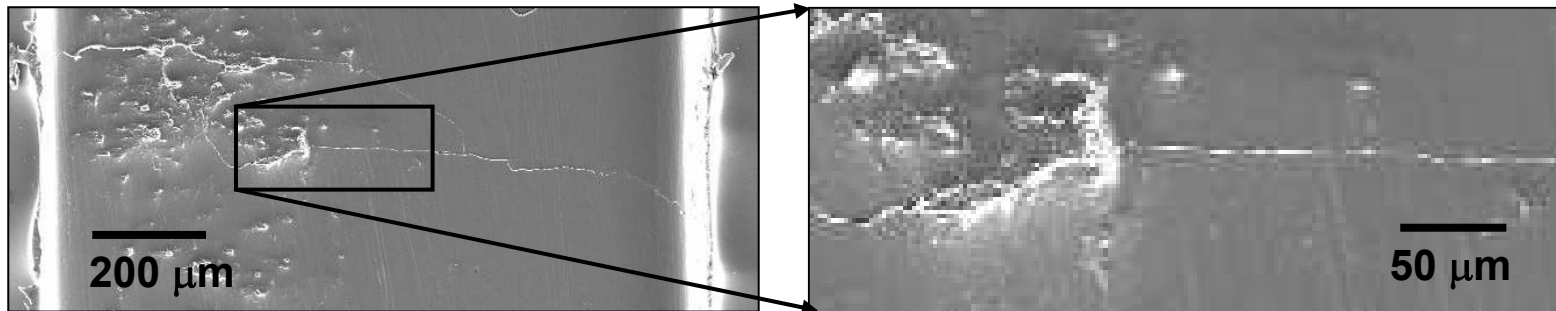
Specimen (no load) – 27 μm

CRACK DETECTION AFTER POLISHING

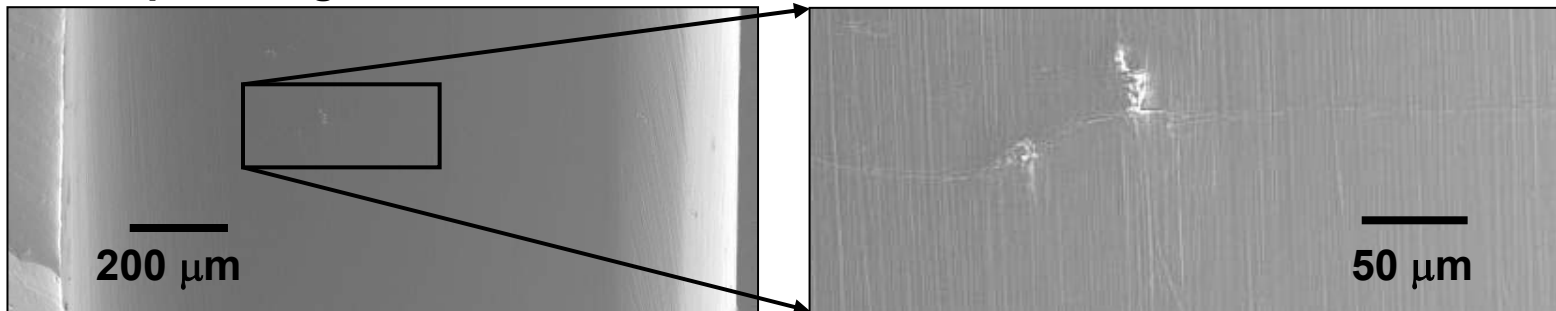
- **Flowliner slots were polished after cracks detected in 2002**
- **One orbiter has not flown since flowliner slot polishing**
- **Concern about post-polishing crack detection**
 - **Crack mouth potentially filled with material**

POLISHED CRACK DETECTION

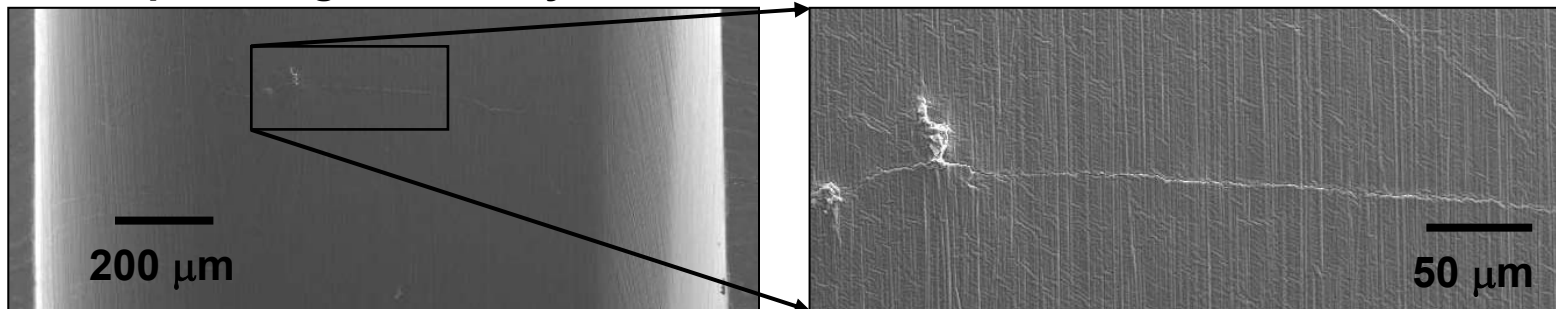
Initial crack



After polishing

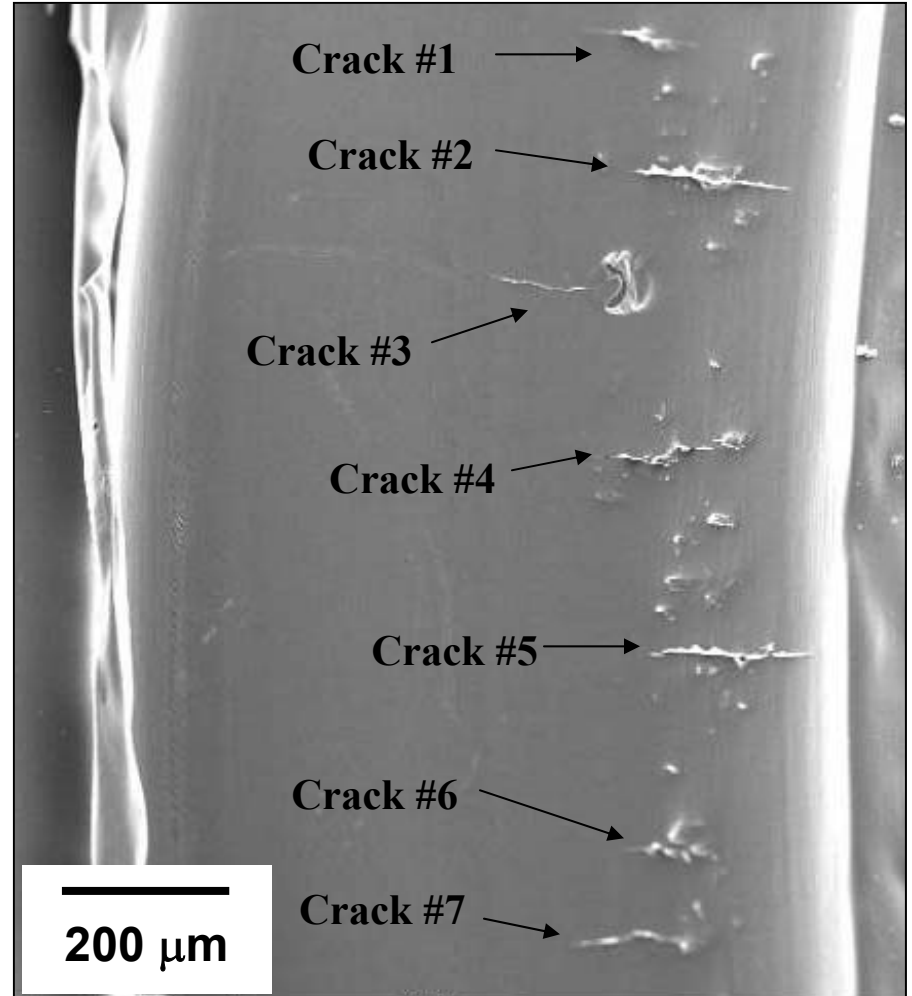


After polishing + 1 load cycle

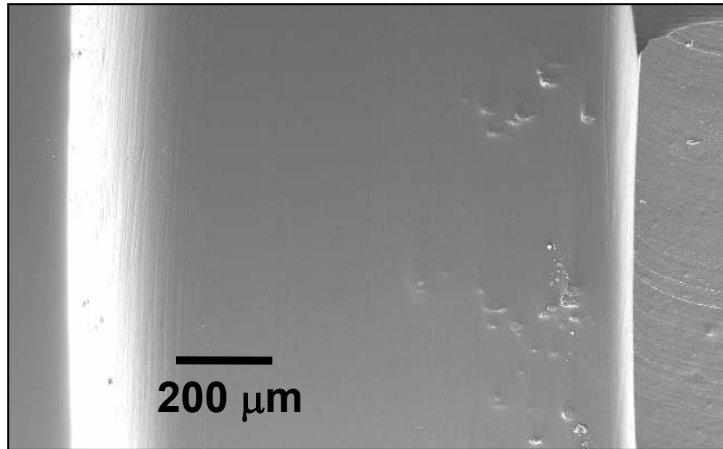


SURFACE FINISH QUALITY

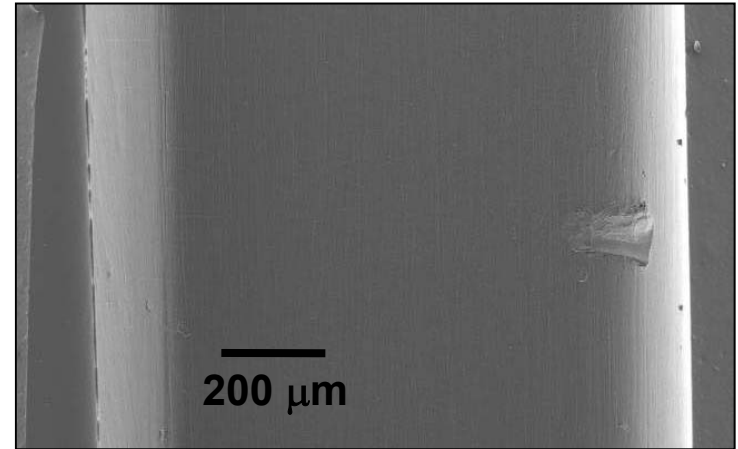
- **Pit-like damage from punching not completely removed by polishing**
- **At least 7 fatigue cracks initiated by 50,000 cycles**
- **Quality of surface finish is important**



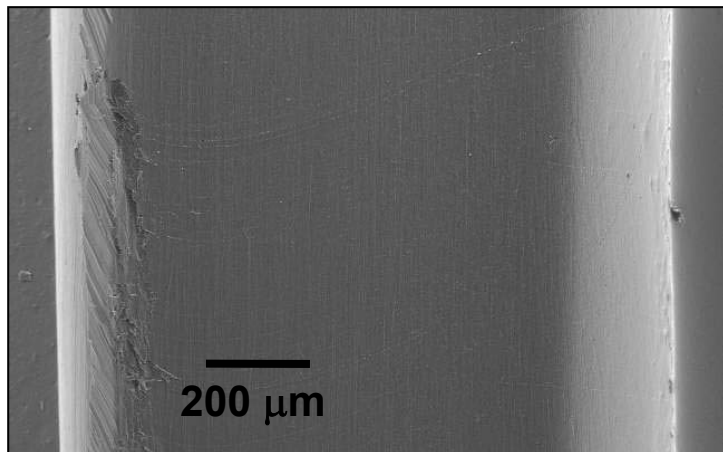
OTHER TYPES OF DAMAGE



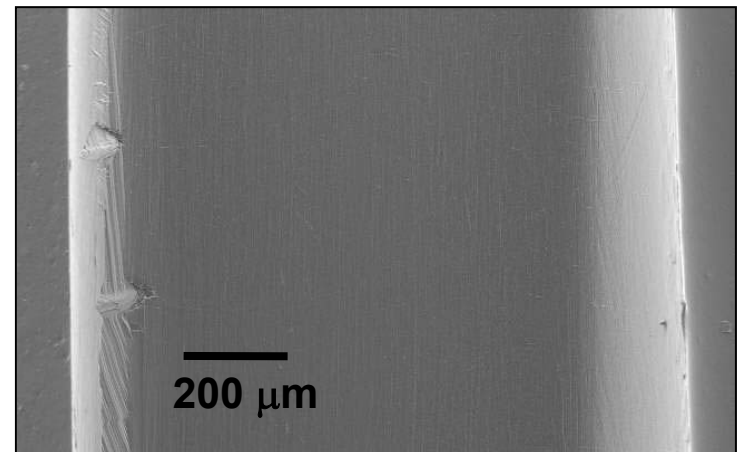
Pit damage



Tool mark



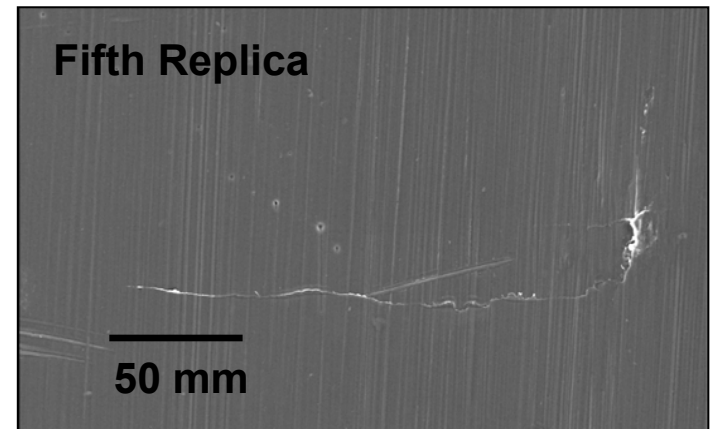
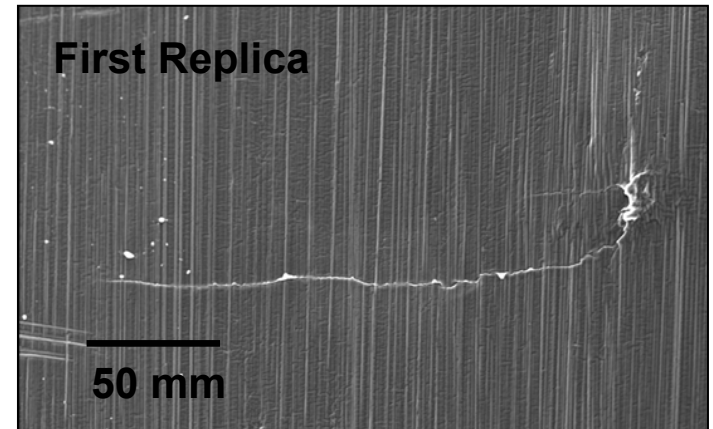
Abrasion and scratches



Tool marks/dents

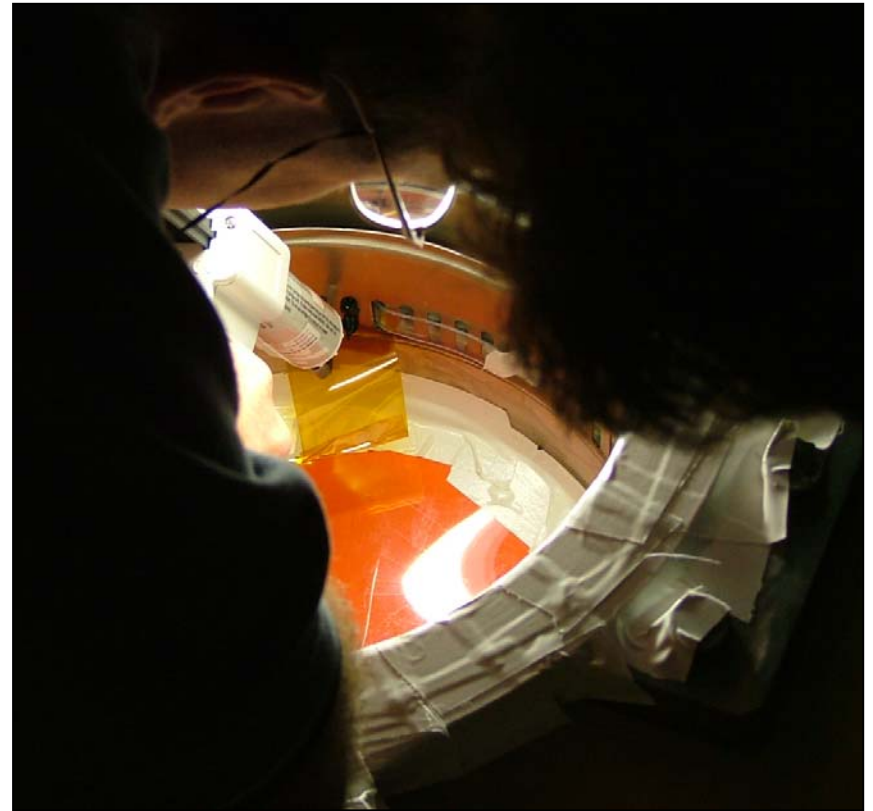
REPRODUCIBILITY

- **Concern: Repeated replication may fill crack mouth**
- **Repeated replicas taken on several cracked specimens**
 - **Example: 0.006-inch-long surface crack**
- **No degradation in crack detection**



APPLICATION

- **Replica-based inspection method approved for use on flight hardware**
- **Found 55 cracks in 3 orbiters**
 - Ranging from 0.004 to 0.040 inches
- **Confirmed repair by second round of replicas**



OTHER APPLICATIONS

- **Replica-based crack inspection may be well-suited for other applications**
 - **Improved crack detection could make damage tolerance life management practical for additional components**
 - **Rotorcraft ?**
 - **Propellers ?**
 - **HCF engine components?**

PROS AND CONS

PROS

- Much better resolution than traditional NDE
- Little training required to make replicas
- Limited equipment needed in field

CONS

- More labor intensive than traditional NDE
- Limited to surface flaws
- Dependent on surface condition
- Limited to small areas
- No immediate feedback

SUMMARY

- **Analysis of silicone-based replicas**
 - Find cracks below 0.005 inches
 - Find pits/defects down to 0.001 inches
- **Method approved for use on flight hardware**
 - Found 55 cracks in 3 orbiters (684 slots)
 - Identified unacceptable levels of damage
 - Repair confirmed by second round of replicas